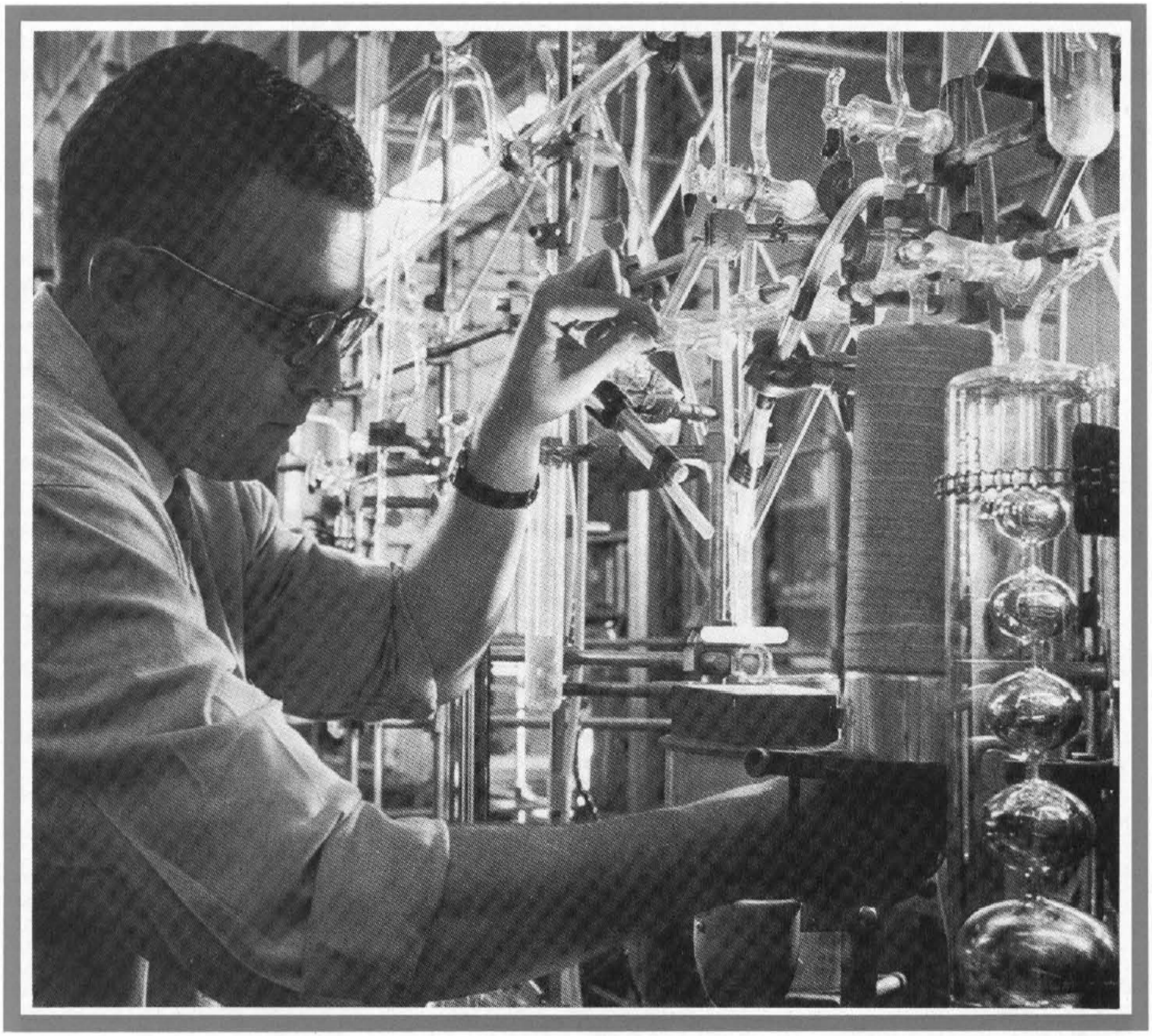

Liquid Propellant for Cannon Artillery?

by CPT Joseph W. Silbaugh Jr.

Not only was Leonardo da Vinci a painter, sculptor, architect, and engineer, but he was also a designer of military hardware with many ideas that were hundreds of years ahead of the times. He was keenly interested in the art of artillery and designed a self-propelled cannon, a fin-stabilized rocket, a machinegun, and a covered armored car. Yet, if he returned today, he would probably be awed at the dramatic developments since the 15th century.

In his article, "Field Artillery of the 1980s" (*National Defense*, May-June 1978), MG Jack N. Merritt (former Commandant of the US Army Field Artillery School) draws us a picture of a highly sophisticated battlefield where TACFIRE (Tactical Fire Direction System and its microprocessor computer technology allow us to break the habit of standard firing unit formations. In addition, Firefinder, BSTAR (Battlefield Surveillance Target Acquisition Radar), and the RPV (Remotely Piloted Vehicle) will provide accurate target acquisition to TACFIRE which interfaces with FAMAS (Field Artillery Meteorological Acquisition System) and PADS (Position and Azimuth Determining System) to provide precise firing data to individual cannons. Throughout his articles, General Merritt highlights major developments in weapon systems and ammunition, including precision guided projectiles, rockets, and missiles.

Although it is obvious we have improved our vehicles and weapons and refined our target acquisition and fire control methods, we are still using the same basic chemical propulsion technology introduced centuries ago. For that reason, the concept of using a liquid instead of a solid propellant in artillery cannon is currently under study. As with any new system, there may be some innate resistance to change as well as unforeseen difficulties, but the potential advantages to the Army, other services, and the country as a whole make the project worthwhile. Even though the move from solid to liquid propellant (LP) is a radical shift in cannon propulsion technology, the concept in itself has "been around" for some time.

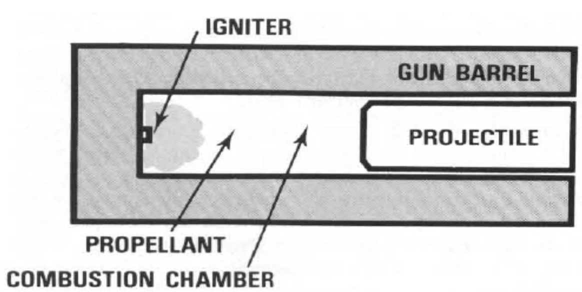

Figure 1. Bulk loaded liquid propellant gun.

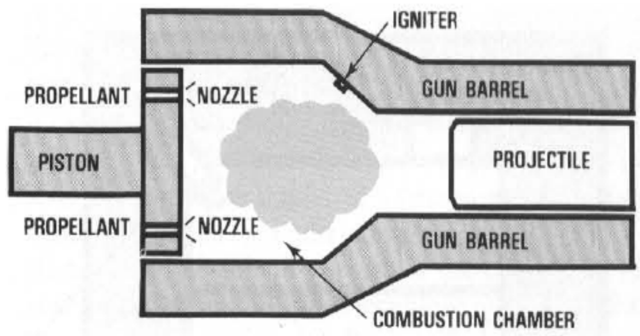

Figure 2. Direct injected regeneratively pumped liquid propellant gun.

What is a liquid propellant gun?

Basically, there are two types of liquid propellant guns (LPGs): the bulk loaded (figure 1) and the direct injected regeneratively pumped (figure 2).

Until about four years ago, the bulk loaded liquid propellant gun (BLPG) was the kind most extensively researched. In this type weapon the chamber behind the projectile is filled completely with liquid propellant, and the propelling charge is usually ignited at the rear. The present BLPGs, however, suffer from erratic combustion and do not produce the same ballistics with each firing.

In the direct injected regeneratively pumped gun (RLPG), the propellant is pumped through orifices in a differential area piston during the combustion cycle so that the rate at which the propellant is injected into the combustion chamber is controlled. As the piston moves back, liquid is injected into the combustion chamber; thus, the faster the piston moves back, the faster the liquid propellant is sprayed into the combustion chamber where ignition and combustion are continuously taking place until the fuel is burned. The rate at which the liquid propellant is metered into the combustion chamber controls the rate of combustion and thus the pressure. Muzzle velocity and range are controlled by the stroke of the piston, chamber pressure, and in-tube projectile travel.

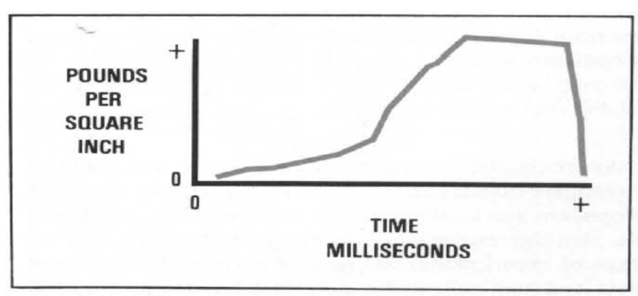

Figure 3. Propellant pressure time curve.

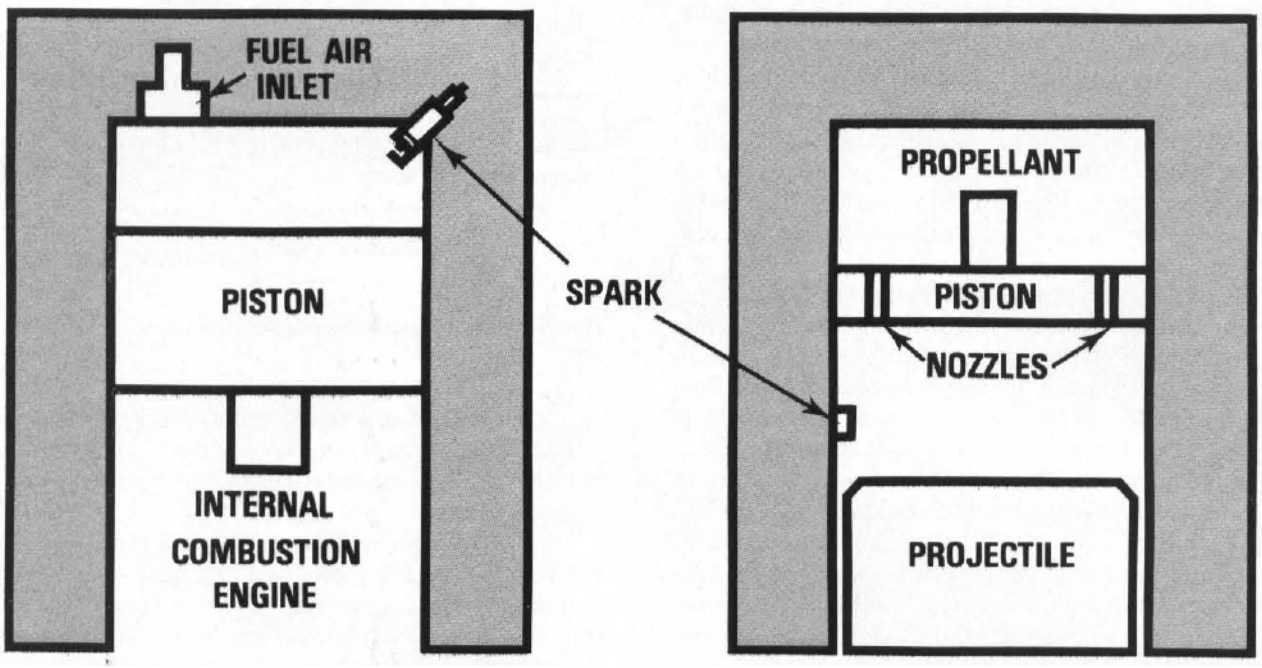

Figure 4. Internal combustion engine operation.

For example, the more liquid propellant used, the higher the muzzle velocity and the longer the range (shown by the pressure time curve in figure 3); conversely, the less liquid propellant used, the lower the muzzle velocity and the shorter the range. The pressure time curve also shows that, for a short time, there is almost a steady state of combustion, which generally provides more efficient use of energy from the propelling charge. To illustrate the operation more simply, consider an internal combustion engine in which the carburetor injects the combined fuel-air (oxygen) mixture into the cylinder; the spark ignites the mixture and the piston is driven down by the force of the explosion (figure 4). Instead of a carburetor, in the regeneratively injected liquid propellant gun, the holes in the piston meter the liquid propellant into the combustion chamber where a spark ignites the liquid propellant and forces the projectile from the tube.

Note: *Only the direct injected regeneratively pumped method is considered here because General Electric Corporation (who is conducting a study on the use of liquid propellants under an Army sponsored contract) has reportedly demonstrated much better control using the RLPG rather than the BLPG.*

Background

Approximately 20 years ago, a decision was made to investigate caseless ammunition rather than study liquid propellant gun technology. By the late 1950s, combustible cartridge exploratory development had reached the stage of experimental testing in a variety of heavy tank guns and had indicated a potential for use in armored weapon systems. History and the Congressional Record indicate that this program was plagued with failures and that caseless ammunition proved to be unsatisfactory.

In the early 1970s, both the United States Navy and the Defense Advanced Research Project Agency (DARPA) had intensive programs directed toward the immediate application of liquid propellant guns. The Gruman Aerospace Corporation study for the Navy indicated that a liquid propellant gun would be efficient and effective for use in an air-to-air role and would have a 300 percent increase in kill probability over the current 20-mm Vulcan M61A1 cannon. However, in late 1976, the prime contractor for DARPA experienced two catastrophic failures in a bulk loaded liquid monopropellant gun system, and Congress demanded that DARPA terminate its demonstration program. Also, in late 1976, Congress denied funds for further work on a Navy BLPG and, in the spring of 1977, removed monies from the Air Force budget for a BLPG demonstration program. The Air Force subsequently awarded two contracts (one to Ford Aerospace and one to General Electric) to develop a more conventional cannon rather than conduct additional research on a liquid propellant gun.

Currently, the US Army Ballistics Research Laboratory is conducting a small in-house research program on monopropellants, basically aimed toward supporting a General Electric Corporation contract sponsored by the Advanced Concept Team (ACT) with the Ballistics Research Laboratory (Alberdeen Proving Ground, MD) acting as monitor. General Electric is investigating the applicability of the regeneratively injected process to high pressure, liquid propellant guns. This study will establish the technical data base needed for eventual application to artillery cannon.

Success in developing a liquid propellant gun would have considerable impact on the Army's medium and large caliber weapons systems. A liquid propellant tank gun system is, however, out of the question at this time since ammunition design decisions for the XM1 (the tank of the 1980s) are almost totally fixed. Once the capabilities of the RLPG are demonstrated, extension to the higher operating pressures required for a tank gun may be more seriously pursued. At the present time, however, the ballistic characteristics of the RLPG are more suited for larger caliber weapons with lower operating pressures and extremely well-controlled muzzle velocities. Since artillery calibers (105-mm, 155-mm, and 8-inch) have remained essentially the same since World War II, one of these calibers would seem a likely candidate for the application of the RLPG technology. Although there is currently a great emphasis on self-propelled artillery, recent improvements in self-propelled artillery basically have centered on adaptations and modifications of existing weapons systems to achieve higher mobility (by reducing weight) and longer ranges (by using different solid propellant charges and longer tubes).

New concepts in artillery

As General Merritt stated in his article ("Field Artillery in the 1980s"), "The Field Artillery System will furnish the combined arms teams the versatile, destructive firepower it needs" (i.e., if the combat industrial developers can field the various pieces of equipment).

What is being considered is a totally different type of technology which would have far-reaching advantages in the total Field Artillery System as well as multiservice applications. First, let us compare liquid and solid propellants.

It is fairly common knowledge that our solid propellants are produced in government owned and contractor operated (GOCO) plants and that the environmental impact of their production is significant. Also, since several critical materials and high amounts of energy are required in the production of solid propellants, they are extremely sensitive and must be handled with great care.

In contrast, the liquid propellants under study are of hydroxyl ammonium nitrate (HAN), fuel-nitrate, and water solutions which we will refer to as LPX. The elements required to produce LPX are not costly, and the production process is basically a non-polluting electrolysis (unlike our current ammunition plants). Since a low amount of energy is required to produce LPX, the cost should be considerably less than that of current ammunition.

How safe is LPX?

LPX is relatively safe (almost too safe) since the normal flammability hazards associated with ammunition production, storage, and shipment are not present. Unlike most liquid and solid propellants, LPX will not support a flame at atmospheric pressure (this does not mean it cannot be ignited). HAN-based liquid propellant will react at atmospheric pressure, but only with slow, low-level energy release similar to a fizz burn. On the other hand, LPX must be under considerable pressure to be ignited to flame combustion and is therefore quite suitable for use in cannon. Another unique quality of LPX is that it is water soluble. If LPX is spilled or becomes decomposed, water can be used to flush the contaminated area which makes this propellant simpler to handle and ideal for naval applications.

In case of demilitarization, solid propellants are costly to destroy. Chemically, LPX can be diluted easily and inexpensively and might even be sold as a high grade nitrate fertilizer, thereby diminishing the cost of demilitarization significantly.

Advantages

As previously mentioned, the systems probably most affected at first would be self-propelled artillery. Possible advantages associated with a liquid propellant direct injected regeneratively pumped gun system are as follows (figure 5):

ACCEPTED ADVANTAGES

- Safety
- Reduced vulnerability
- Increased volumetric impetus
- Continuous zoning
- Simplified logistics
- Increased on-board storage
- Simplified loading
- Elimination of cartridge case
- Reduced muzzle flash
- Improved weight distribution (important in aircraft)
- Increased ammunition carrying capacity

POTENTIAL ADVANTAGES

- Reduced wear and erosion
- Increased rate of fire
- Adaptability to existing projectiles and barrels
- Production ease
- Lower cost to produce
- Lower energy requirement in production
- No critical materials required in production
- Demilitarization (low cost)
- Use after demilitarization as high nitrate fertilizer
- Reduced storage cost
- Reduced transportation and handling cost
- Reduced packaging and preservation cost
- System design (external storage)

DISADVANTAGES

- New field
- Not as much technical data available
- No direct correlation to rocketry

Figure 5. Advantages and disadvantages of liquid propellant.

• Battlefield survivability may be increased because liquid propellants appear to be less sensitive to outside ignition than presently fielded solid propellants. (Liquid propellants could be externally pumped and stored.)

• An increased ammunition carrying capability might result because of additional storage volume since, on a volume basis, there is much more energy available in liquid propellant than in the same volume of perforated solid propellant. This is extremely important for system design and also illustrates the increased volumetric impetus of LPX.

• This leads to a key advantage: That of continuous zoning instead of fixed zones. The amount of liquid propellant injected into the chamber can be metered precisely; e.g., you could call in zone 4.5576 and get more accuracy from the weapon system. With some redesign and reprogramming, TACFIRE and other battlefield computers might provide a means for easy implementation of continuous zoning.

• Similarly, the rate of fire may be enhanced because only the projectile has to be handled manually. Therefore, system design and automatic loading could be simplified. For example, suppose the gun had to return to zero elevation for the automatic loader to function; perhaps only the projectile would have to be loaded in zero elevation and the gun could be elevated as the programming is set for the liquid propellant charge.

• The brass or spiral wrap cases (105-mm and other tank guns) could be eliminated.

• Another advantage lies in reduced muzzle flash. Because solid propellants are very fuel rich, there is some loss of energy when a charge is fired. In fact, less than half the propellant energy is normally imparted to the projectile as it leaves the tube. The hot fuel rich gases speeding out of the tube burn vigorously when mixed with outside air, causing a large secondary flash. With liquid propellant, there should be no secondary flash because the fuel-to-oxidizer ratio is basically one; therefore, no fuel rich gases will burn off at the end of the tube.

• Because the gases of a solid propellant are so hot, a thin layer of the tube is actually melted each time a weapon is fired. LPX gases are lower in temperature; thus there should be reduced tube wear and erosion. More study is necessary, however, to determine the exact effects of liquid propellant on tube life.

• General Electric Ordnance System engineers indicated that existing tubes could be adapted to the new liquid propellant system, thus reducing the cost compared with developing a new system.

• With quick disconnect couplings and our experience in handling liquids, resupply should be expedited.

Disadvantages

The biggest advantage lies in a lack of sufficient data available to the field. There is no correlation to the low pressure data obtained with rockets using liquid propellants.

Adequate understanding of the high pressure combustion process and potential explosive hazards must be achieved prior to moving on to the larger scale testing. Operational requirements such as performance, size, weight, safety, and reliability must be taken into account in developing configurations that have potential for ultimate operational feasibility. Propellant loading methods and ignition techniques are also factors which require further consideration and investigation.

Conclusions

Thus far, the possibilities of a liquid propellant gun look especially attractive, considering performance, cost, projected ease of implementation, and potential benefit (not only for the military, but also for our environment and economy). The energy savings alone in production of liquid compared to solid propellants appear to be significant and worthy of further investigation.

In the final analysis, liquid propellant gun technology is just scratching the surface but, with continued interest and research, could open a whole new flexibility in system design. As we've seen pointed out in other *Journal* articles, "Let's find out."

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